DECLARATION

I, the undersigned, of 2-12, Nakazaki 2-chome, Kita-ku, Osaka, Japan, hereby certify that I am well acquainted with the English and Japanese languages, that I am an experienced translator for patent matter, and that the attached document is a true English translation of

Japanese Patent Application No. **9-015382**

that was filed in Japanese.

I declare that all statements made herein of may own knowledge are true, that all statements on information and belief are believed to be true, and that these statements were made with the knowledge that willful statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Signature:

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[Name of the Document] SPECIFICATION

[Title of the Invention] Method for evaluating semiconductor device, method and apparatus for heat-treating the same, and method for controlling heat-treating apparatus

[Claims]

[Claim 1] A method for evaluating a semiconductor device characterized by comprising the steps of:

monitoring optical properties of an n-type semiconductor region of a semiconductor device which has been subjected to at least impurity doping involving a heat treatment; and

evaluating an impurity concentration in the n-type semiconductor region based on the optical properties obtained by the step.

[Claim 2] The method for evaluating a semiconductor device of Claim 1, characterized in that the step of monitoring the optical properties comprises the steps of:

irradiating measurement light onto the n-type semiconductor region;

intermittently irradiating exciting light onto the n-type semiconductor region; and

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the n-type semiconductor region depending upon whether or not the exciting light has been irradiated onto the n-type semiconductor region by a reflectivity of the

measurement light from the n-type semiconductor region in the case where the exciting light has not been irradiated.

[Claim 3] The method for evaluating a semiconductor device of Claim 2, characterized in that, in the step of calculating the variation amount of the reflectivity,

the variation amount of the reflectivity of the measurement light in a wavelength range from 300 to 600 nm is calculated.

[Claim 4] The method for evaluating a semiconductor device of Claim 2, characterized in that, in the step of calculating the variation amount of the reflectivity,

the variation amount of the reflectivity of the measurement light at a particular energy value of the measurement light providing a relative minimum value in a spectrum of the variation amount of the reflectivity of the measurement light is calculated.

[Claim 5] The method for evaluating a semiconductor device of Claim 4, characterized in that

the particular energy value of the measurement light is any value included within a range of 3.2 to 3.6 eV.

[Claim 6] A method for heat-treating a semiconductor device including an n-type semiconductor region, in which a structural disorder has been generated during a process, characterized by comprising the steps of:

monitoring optical properties of the n-type semiconductor region; and

performing a heat treatment for recovering the structural disorder of the n-type semiconductor region, while controlling conditions based on the optical properties obtained by the step.

[Claim 7] The method for heat-treating a semiconductor device of Claim 6, characterized in that the step of monitoring the optical properties comprises the steps of:

irradiating measurement light onto the n-type semiconductor region;

intermittently irradiating exciting light onto the n-type semiconductor region; and

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the n-type semiconductor region depending upon whether or not the exciting light has been irradiated onto the n-type semiconductor region by a reflectivity of the measurement light from the n-type semiconductor region in the case where the exciting light has not been irradiated.

[Claim 8] The method for heat-treating a semiconductor device of Claim 7, characterized in that, in the step of calculating the variation amount of the reflectivity,

the variation amount of the reflectivity of the measurement light in a wavelength range from 300 to 600 nm is calculated.

[Claim 9] The method for heat-treating a semiconductor device of Claim 7, characterized in that, in the step of calculating the variation amount of the reflectivity,

the variation amount of the reflectivity of the measurement light at a particular energy value of the measurement light providing a relative minimum value in a spectrum of the variation amount of the reflectivity of the measurement light is calculated.

[Claim 10] The method for heat-treating a semiconductor device of Claim 9, characterized in that

the particular energy value of the measurement light is any value included within a range of 3.2 to 3.6 eV.

[Claim 11] The method for heat-treating a semiconductor device of Claim 7, 8, 9 or 10, characterized in that, in the step of performing the heat treatment on the n-type semiconductor region,

the heat treatment is completed when the variation amount of the reflectivity of the measurement light reaches a predetermined value.

[Claim 12] The method for heat-treating a semiconductor device of Claim 6, further comprising

a step of evaluating an impurity concentration in the n-type semiconductor region based on the optical properties obtained by the step of monitoring the optical properties,

characterized in that, in the step of performing the heat treatment, the semiconductor device is subjected to the heat

treatment until the impurity concentration in a predetermined site, which has been obtained by the step, reaches a desired value.

[Claim 13] The method for heat-treating a semiconductor device of Claim 12, characterized in that the step of monitoring the optical properties comprises the steps of:

irradiating measurement light onto the n-type semiconductor region;

intermittently irradiating exciting light onto the n-type semiconductor region; and

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the n-type semiconductor region depending upon whether or not the exciting light has been irradiated onto the n-type semiconductor region by a reflectivity of the measurement light from the n-type semiconductor region in the case where the exciting light has not been irradiated.

[Claim 14] An apparatus for heat-treating a semiconductor device characterized by comprising:

a processing chamber for housing a substrate having a semiconductor region;

heating means for heating at least the semiconductor region for heat treatment with the substrate disposed within the processing chamber;

first light incidence means for intermittently irradiating exciting light onto the semiconductor region of the substrate within the processing chamber;

second light incidence means for irradiating measurement light onto the semiconductor region of the substrate within the processing chamber;

reflected light detection means for detecting reflected light of the measurement light from the semiconductor region of the substrate within the processing chamber;

calculation means for receiving an output of the reflected light detection means and calculating a variation amount of the reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated from the first light incidence means; and

control means for receiving an output of the calculation means and for controlling an operation of the heating means based on the variation amount of the reflectivity of the measurement light.

[Claim 15] The apparatus for heat-treating a semiconductor device of Claim 14, characterized in that

the second light incidence means comprises a Xe lamp as a light source of the measurement light.

[Claim 16] The apparatus for heat-treating a semiconductor device of Claim 14 or 15, characterized in that

the first light incidence means comprises an Ar ion laser or an He-Ne laser as a light source of the exciting light.

[Claim 17] The apparatus for heat-treating a semiconductor device of Claim 14, 15 or 16, characterized in that

the reflected light detection means measures the measurement light in a wavelength range from 300 nm to 600 nm.

[Claim 18] The apparatus for heat-treating a semiconductor device of Claim 14, 15, 16 or 17, characterized in that

the reflected light detection means is configured so as to monitor the reflected light having a particular wavelength by using a light filter.

[Claim 19] The apparatus for heat-treating a semiconductor device of Claim 18, characterized in that

the light filter cuts off light having a wavelength of 400 nm or less.

[Claim 20] The apparatus for heat-treating a semiconductor device of Claim 14, 15, 16, 17, 18 or 19, characterized in that

the apparatus for heat-treating is a single wafer processing heat-treating apparatus for performing a heat treatment on a single substrate having the semiconductor region every time,

and that the control means measures an impurity concentration in the semiconductor region based on the variation of the reflectivity calculated by the calculation means and stops the operation of the heating means when the impurity concentration reaches a desired value.

[Claim 21] A method for controlling a heat-treating apparatus, the heat-treating apparatus including: a processing chamber for housing a substrate having a semiconductor region; heating means for heating at least the semiconductor region for heat treatment with the substrate disposed within the processing chamber; first light incidence means for intermittently irradiating exciting light onto the semiconductor region of the substrate within the processing chamber; second light incidence means for irradiating measurement light onto the semiconductor region of the substrate within the processing chamber; and reflected light detection means for detecting reflected light of the measurement light from the semiconductor region of the substrate within the processing chamber, the method characterized by comprising the steps of:

irradiating the measurement light onto the semiconductor region;

intermittently irradiating the exciting light onto the semiconductor region;

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the semiconductor region depending upon whether or not the exciting light has been irradiated onto the semiconductor region by a reflectivity of the measurement light from the semiconductor region in the case where the exciting light has not been irradiated onto the semiconductor region;

controlling the heat treatment such that the heating means is operated until the variation amount of the reflectivity, calculated in the step, reaches a predetermined value; and

monitoring the predetermined time in the step of controlling the heat treatment and giving a command to perform a maintenance on the heat-treating apparatus if the predetermined time exceeds a critical value.

[Claim 22] The method for controlling a heat-treating apparatus of Claim 21, characterized in that

the second light incidence means comprises a Xe lamp as a light source of the measurement light.

[Claim 23] The method for controlling a heat-treating apparatus of Claim 21 or 22, characterized in that

the first light incidence means comprises an Ar ion laser or an He-Ne laser as a light source of the exciting light.

[Claim 24] The method for controlling a heat-treating apparatus of Claim 21, 22 or 23, characterized in that

the reflected light detection means measures the measurement light in a wavelength range from 300 nm to 600 nm.

[Claim 25] The method for controlling a heat-treating apparatus of Claim 21, 22, 23 or 24, characterized in that

the reflected light detection means is configured so as to monitor the reflected light having a particular wavelength by using a light filter.

[Claim 26] The method for controlling a heat-treating apparatus of Claim 25, characterized in that

the light filter cuts off light having a wavelength of 400 nm or less.

[Claim 27] The method for controlling a heat-treating apparatus of Claim 21, 22, 23, 24, 25 or 26, characterized in that

the semiconductor region is an n-type semiconductor region.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to technologies for evaluating the characteristics of a semiconductor device in a process and also relates to technologies for controlling a heat treatment process for the semiconductor device by utilizing the evaluation results.

[0002]

[Prior Art]

In recent years, semiconductor integrated circuits have achieved a remarkably high degree of integration. Thus, in semiconductor devices constituting a semiconductor integrated circuit, efforts have also been made in order to develop a MOS transistor or the like having an even smaller size and an even higher performance. Now that semiconductor devices, such as a MOS transistor, having such a very small size and such a very high performance have been provided, it is important to maintain high reliability for the semiconductor devices.

[0003]

Herein, of the processes for forming the individual components of a semiconductor device, the impurity introduction technology, for example, is an important process determining the operational characteristics of the semiconductor device. An ion implantation method, in which impurity ions are implanted into a semiconductor substrate, an electrode or the like by making an electric field accelerate the ions, is a mainstream method of the impurity introduction. In such a case, impurity ions are generally accelerated with the energy of several tens keV so as to be implanted into the semiconductor substrate or the like. However, as a result of the impurity ion implantation, a damaged layer with disordered crystallinity is generated in the surface layer of the semiconductor substrate or the like. In addition, the impurity has not been activated as carriers, and the concentration distribution of the impurity has not achieved a desired distribution state. Thus, in order to activate the impurity, recover the damage, and optimize the profiles, a heat treatment (annealing) is performed after ions have been implanted. Conventionally, the annealing process time, temperature and the like have been determined by optimizing the design (device simulation) and conditions. In principle, conditions for annealing have been set based on experience. An annealing process for recovering the surface defective layer of the semiconductor substrate has had a particular dependence on experience.

[0004]

[Problems to be Solved by the Invention]

However, as a result of the remarkable size reduction and performance enhancement of a MOS transistor or the like, the number of components of a semiconductor device has been increased and the size of each component has become very small. Consequently, the degradation in reliability of a semiconductor device has become a problem. Specifically, in the circumstances where the size of each component of a semiconductor device has become smaller and smaller and the impurity introduction into a very small region and the profile control thereof have become more and more important, if the annealing conditions are still set based on experience as in the above-described conventional method, then it is not uncommon to result in a non-optimum profile or to bring about such a trouble that the process is completed with defects left in the semiconductor substrate. In addition, even though it is earnestly demanded to shorten a period required for developing a desired semiconductor device, if the optimization of the annealing conditions still depends on a conventional procedure repeatedly performing processing, analysis, processing and analysis, etc., then the development efficiency is considerably decreased. Thus, the process control technologies in accordance with on-the-spot observation of the annealing treatment process have recently been demanded earnestly.

[0005]

Moreover, in the case of performing a heat treatment by using a single wafer processing heat-treating apparatus, subtle variations have been caused in the heat treatment amounts among wafers owing to the difference in characteristics among the heat-treating apparatuses and the time-dependent variations thereof, unlike a conventional batch-type one.

[0006]

Furthermore, it has been difficult to precisely know an actual dose during the impurity introduction and an effective concentration of the impurity which has been introduced into the substrate after the heat treatment has been performed.

[0007]

The present invention has been devised for solving these problems, and the objectives thereof are to know a variation in physical properties and an impurity concentration by monitoring the optical properties in an annealing process for recovering a semiconductor region having physical properties, which have been disordered by the introduction of an impurity or the like, while paying attention to a correlation between the variation in reflectivity of light and the properties of the semiconductor region, and to control a process based on the result.[0008]

[Means for Solving the Problems]

In order to accomplish the above-described objectives, the present invention takes various means regarding a method for evaluating a semiconductor device which are recited in Claims 1

to 5, various means regarding a method for heat-treating a semiconductor device which are recited in Claims 6 to 15, various means regarding an apparatus for heat-treating a semiconductor device which are recited in Claims 16 to 20 and various means regarding a method for controlling a heat-treating apparatus which are recited in Claims 21 to 27.

[0009]

As recited in Claim 1, the method for evaluating a semiconductor device of the present invention includes the steps of: monitoring optical properties of an n-type semiconductor region of a semiconductor device which has been subjected to at least impurity doping involving a heat treatment; and evaluating an impurity concentration in the n-type semiconductor region based on the optical properties obtained by the step.

[0010]

In accordance with this method, information about the impurity concentration in the vicinity of the surface of the n-type semiconductor region can be obtained by utilizing the fact that the penetration depth of light into a semiconductor substrate is shallow. Thus, the impurity concentration in the n-type semiconductor region can be sensed precisely during a fabrication process at a point in time immediately after the impurity ions have been implanted or at an arbitrary point in time during an impurity diffusion process using heat treatment after ions have been implanted, for example, without decreasing the

sensitivity or increasing noise in accordance with the information from the inside of the n-type semiconductor region.

[0011]

As recited in Claim 2, the step of monitoring the optical properties of Claim 1 may include the steps of: irradiating measurement light onto the n-type semiconductor region; intermittently irradiating exciting light onto the n-type semiconductor region; and calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the n-type semiconductor region depending upon whether or not the exciting light has been irradiated onto the n-type semiconductor region by a reflectivity of the measurement light from the n-type semiconductor region in the case where the exciting light has not been irradiated.

[0012]

When exciting light is irradiated into the n-type semiconductor region, carriers in the n-type semiconductor region are excited. And the intensity of the electric field is varied in accordance with the increase in number of carriers. Thus, the reflectivity of the measurement light is also varied, i.e., increased or decreased. And the higher the impurity concentration is, the larger the increase in number of carriers is. Therefore, in accordance with this method, the impurity concentration in the n-type semiconductor region can be detected

based on the variation amount of the reflectivity of the measurement light.

[0013]

As recited in Claim 3, in the step of calculating the variation amount of the reflectivity of Claim 2, the variation amount of the reflectivity of the measurement light in a wavelength range from 300 to 600 nm is preferably calculated.

[0014]

In accordance with this method, only the impurity concentration in a region causing a problem in a semiconductor device can be detected with certainty by utilizing a fact that the measurement light in a visible light region, in particular, has a property of penetrating a semiconductor into a depth of several tens nm.

[0015]

As recited in Claim 4, in the step of calculating the variation amount of the reflectivity of Claim 2, the variation amount of the reflectivity of the measurement light at a particular energy value of the measurement light providing a relative minimum value in a spectrum of the variation amount of the reflectivity of the measurement light is preferably calculated.

[0016]

In accordance with this method, the impurity concentration in the n-type semiconductor region can be detected easily, rapidly and precisely, while utilizing a characteristic shape of

the spectrum of the variation amount of the reflectivity of the measurement light.

[0017]

As recited in Claim 5, the particular energy value of the measurement light of Claim 4 is preferably any value included within a range of 3.2 to 3.6 eV.

[0018]

As recited in Claim 6, the method for heat-treating a semiconductor device of the present invention is a method for heat-treating a semiconductor device including an n-type semiconductor region, in which a structural disorder has been generated during a process, and includes the steps of: monitoring optical properties of the n-type semiconductor region; and performing a heat treatment for recovering the structural disorder of the n-type semiconductor region, while controlling conditions based on the optical properties obtained by the step.

[0019]

In accordance with this method, information about the structural disorder in the vicinity of the surface of the n-type semiconductor region can be obtained by utilizing the fact that the penetration depth of light into a semiconductor substrate is shallow, and a heat treatment process can be controlled by utilizing this information. Thus, the normal properties of the n-type semiconductor region can be recovered under appropriate processing conditions not adversely affecting the characteristics of a semiconductor device, while precisely

sensing the structural disorders, such as crystallographic defects and deviation of the electron structure from a normal state in the n-type semiconductor region during a heat treatment process, without decreasing the sensitivity or increasing noise in accordance with the information from the inside of the n-type semiconductor region.

[0020]

As recited in Claim 7, the step of monitoring the optical properties of Claim 6 may include the steps of: irradiating measurement light onto the n-type semiconductor region; intermittently irradiating exciting light onto the n-type semiconductor region; and calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the n-type semiconductor region depending upon whether or not the exciting light has been irradiated onto the n-type semiconductor region by a reflectivity of the measurement light from the n-type semiconductor region in the case where the exciting light has not been irradiated.

[0021]

When exciting light is irradiated into the n-type semiconductor region, carriers in the n-type semiconductor region are excited. And the intensity of the electric field is varied in accordance with the increase in number of carriers. Thus, the reflectivity of the measurement light is also varied, i.e., increased or decreased. And, the period during which the carri-

ers are in an excited state has certain longevity. The more the structure, to be a carrier-trapping layer in the n-type semiconductor region, is disordered, the shorter the longevity becomes and the smaller the variation amount of the reflectivity becomes. Thus, in accordance with this method, the degree of recovery of the n-type semiconductor region can be controlled with certainty by monitoring the reflectivity of the measurement light.

[0022]

As recited in Claim 8, in the step of calculating the variation amount of the reflectivity of Claim 7, the variation amount of the reflectivity of the measurement light in a wavelength range from 300 to 600 nm is preferably calculated.

[0023]

In accordance with this method, the recovery state of the n-type semiconductor region can be controlled based on the information about a region causing a problem in a semiconductor device by utilizing the fact that the measurement light in a visible light region has a property of penetrating a semiconductor into a depth of several tens nm.

[0024]

As recited in Claim 9, in the step of calculating the variation amount of the reflectivity of Claim 7, the variation amount of the reflectivity of the measurement light at a particular energy value of the measurement light providing a rela-

tive minimum value in a spectrum of the variation amount of the reflectivity of the measurement light is preferably calculated.

[0025]

In accordance with this method, the recovery state of the n-type semiconductor region can be controlled easily, rapidly and precisely, while utilizing the characteristic shape of the spectrum indicating how much the variation amount of the reflectivity has been increased or decreased depending upon the wavelength of the measurement light.

[0026]

As recited in Claim 10, the particular energy value of the measurement light of Claim 9 is preferably any value included within a range of 3.2 to 3.6 eV.

[0027]

As recited in Claim 11, in the step of performing the heat treatment on the n-type semiconductor region in Claim 7, 8, 9 or 10, the heat treatment may be completed when the variation amount of the reflectivity of the measurement light reaches a predetermined value.

[0028]

In accordance with this method, the variation in properties of the n-type semiconductor region among the lots after the heat treatment has been performed can be reduced as much as possible.

[0029]

As recited in Claim 12, a step of evaluating an impurity concentration in the semiconductor region based on the optical properties obtained by the step of monitoring the optical properties is further provided in addition to those of Claim 6, and, in the step of performing the heat treatment, the semiconductor device may be subjected to the heat treatment until the impurity concentration in a predetermined site, which has been obtained by the step, reaches a desired value.

[0030]

In accordance with this method, the variation in impurity concentrations and impurity diffusion states in the n-type semiconductor region among the lots can be reduced as much as possible. Thus, a semiconductor device, in which the impurity concentrations are satisfactorily distributed and in which the characteristics of the respective wafers are not considerably different from each other, can be formed.

[0031]

As recited in Claim 13, the step of monitoring the optical properties of Claim 12 preferably includes the steps of: irradiating measurement light onto the n-type semiconductor region; intermittently irradiating exciting light onto the n-type semiconductor region; and calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the n-type semiconductor region depending upon whether or not the exciting light has been irradiated onto the n-type semiconductor region by a re-

flectivity of the measurement light from the n-type semiconductor region in the case where the exciting light has not been irradiated.

[0032]

As recited in Claim 14, the apparatus for heat-treating a semiconductor device of the present invention includes: a processing chamber for housing a substrate having a semiconductor region; heating means for heating at least the semiconductor region for heat treatment with the substrate disposed within the processing chamber; first light incidence means for intermittently irradiating exciting light onto the semiconductor region of the substrate within the processing chamber; second light incidence means for irradiating measurement light onto the semiconductor region of the substrate within the processing chamber; reflected light detection means for detecting reflected light of the measurement light from the semiconductor region of the substrate within the processing chamber; calculation means for receiving an output of the reflected light detection means and calculating a variation amount of the reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated from the first light incidence means; and control means for receiving an output of the calculation means and for controlling an operation of the heating means based on the variation amount of the reflectivity of the measurement light.

[0033]

This makes it possible to control heat treatment conditions while monitoring the optical properties of a semiconductor region when the semiconductor region of a semiconductor device is heat-treated. Specifically, if there is any structural disorder in the semiconductor region, the longevity of the carriers to be excited by the exciting light becomes short and thus the variation amount of the reflectivity of the measurement light becomes small. By utilizing this phenomenon, the optical properties of the semiconductor region can be grasped with certainty. Thus, by performing a heat treatment while monitoring the properties of a semiconductor region during a heat treatment process, the heat treatment process can be controlled rapidly and precisely, as compared with examining the properties of a semiconductor region by taking out a substrate from a processing chamber after a heat treatment has been performed and then by feeding back the results to the heat treatment conditions, as has been done conventionally.

[0034]

As recited in Claim 15, the second light incidence means of Claim 14 preferably includes a Xe lamp as a light source of the measurement light.

[0035]

As recited in Claim 16, the first light incidence means of Claim 14 or 15 preferably includes an Ar ion laser or an He-Ne laser as a light source of the exciting light.

[0036]

As recited in Claim 17, the reflected light detection means of Claim 14, 15 or 16 preferably measures the measurement light in a wavelength range from 300 nm to 600 nm.

[0037]

These are because of the above-described reasons.

[0038]

As recited in Claim 18, the reflected light detection means of Claim 14, 15, 16 or 17 is preferably configured so as to monitor the reflected light having a particular wavelength by using a light filter.

[0039]

As recited in Claim 19, the light filter of Claim 18 preferably cuts off light having a wavelength of 400 nm or less.

[0040]

As recited in Claim 20, the apparatus for heat-treating of Claim 14, 15, 16, 17, 18 or 19 may be a single wafer processing heat-treating apparatus for performing a heat treatment on a single substrate having the semiconductor region every time, and the control means may measure an impurity concentration in the semiconductor region based on the variation of the reflectivity calculated by the calculation means and may stop the operation of the heating means when the impurity concentration reaches a desired value.

[0041]

This makes it possible to control the impurity concentration in the semiconductor region at a desired value for any

substrate. Thus, it is applicable to the fabrication of a semiconductor device having uniform characteristics which are less varied among the substrates or wafers.

[0042]

As recited in Claim 21, the method for controlling a heat-treating apparatus of the present invention is a method for controlling a heat-treating apparatus including: a processing chamber for housing a substrate having a semiconductor region; heating means for heating at least the semiconductor region for heat treatment with the substrate disposed within the processing chamber; first light incidence means for intermittently irradiating exciting light onto the semiconductor region of the substrate within the processing chamber; second light incidence means for irradiating measurement light onto the semiconductor region of the substrate within the processing chamber; and reflected light detection means for detecting reflected light of the measurement light from the semiconductor region of the substrate within the processing chamber. The method includes the steps of: irradiating the measurement light onto the semiconductor region; intermittently irradiating the exciting light onto the semiconductor region; calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the semiconductor region depending upon whether or not the exciting light has been irradiated onto the semiconductor region by a reflectivity of the measurement light from the semiconductor

region in the case where the exciting light has not been irradiated onto the semiconductor region; controlling the heat treatment such that the heating means is operated until the variation amount of the reflectivity, calculated by the step, reaches a predetermined value; and monitoring the predetermined time in the step of controlling the heat treatment and giving a command to perform a maintenance on the heat-treating apparatus if the predetermined time exceeds a critical value.

[0043]

In accordance with this method, it is possible to monitor the increase in heat treatment time until the variation amount of the reflectivity reaches a predetermined value because of the deterioration of the components within the processing chamber, which deterioration proceeds as the heat-treating apparatus is used longer. Thus, even when the components within the processing chamber are deteriorated, an appropriate heat treatment time can be secured and the generation of defects, resulting from the excessive heat treatment time, in the semiconductor region can be avoided.

[0044]

As recited in Claim 22, the second light incidence means of Claim 21 preferably includes a Xe lamp as a light source of the measurement light.

[0045]

As recited in Claim 23, the first light incidence means of Claim 21 or 22 preferably includes an Ar ion laser or an He-Ne laser as a light source of the exciting light.

[0046]

As recited in Claim 24, the reflected light detection means of Claim 21, 22 or 23 preferably measures the measurement light in a wavelength range from 300 nm to 600 nm.

[0047]

These are because of the above-described reasons.

[0048]

As recited in Claim 25, the reflected light detection means of Claim 21, 22, 23 or 24 is preferably configured so as to monitor the reflected light having a particular wavelength by using a light filter.

[0049]

As recited in Claim 26, the light filter of Claim 25 preferably cuts off light having a wavelength of 400 nm or less.

[0050]

As recited in Claim 27, the semiconductor region of Claim 21, 22, 23, 24, 25 or 26 is preferably an n-type semiconductor region.

[0051]

[Embodiments of the Invention]

(First Embodiment)

Figure 1 is a cross-sectional view schematically showing the configuration of an apparatus for heat-treating a semicon-

ductor device (annealing processing apparatus) in the first embodiment. As shown in Figure **1**, a quartz tube **3** has been attached in a reaction container **7**. A substrate **2** has been placed over the inner surface of the quartz tube **3** via wafer susceptors **2**. On the outer surface of the quartz tube **3**, heaters **4** using infrared rays have been mounted. The substrate **1** in the quartz tube **3** is to be heated by the heaters **4**. Also, a reactive gas inlet port **9** and a reactive gas outlet port **10** are further provided for the reaction container **7**, and the flow rate of the reactive gas is to be appropriately adjusted by a mass flow controller **8**. Also, two quartz windows for observation **5** and **6** are provided through the sides of the reaction container **7** so as to face each other. An n-type semiconductor region **1a** (having a specific resistance of about 0.02 Ωcm) is provided on the substrate **1** and it is configured such that light incident onto the n-type semiconductor region **1a** on the substrate **1** through one quartz window for observation **5** is taken out through the other quartz window for observation **6**. A pattern (having an area of 13×13 mm^2) for optical evaluation has been provided for the n-type semiconductor region **1a** of the substrate **1**, though not shown.

[0052]

Outside the reaction container **7**, a Xe lamp **11** for generating probe light **18** which is measurement light to be incident into the reaction container **7**, an Ar ion laser **12** (having an

output of 1 W) for generating exciting light **20** in the reaction container **7**, a chopper **14** for chopping the exciting light **20** at a frequency of 200 Hz, and a detector **13** for receiving reflected probe light **19** reflected by the n-type semiconductor region **1a** on the substrate **1** and for detecting the intensity thereof, are provided. That is to say, it is configured so as to monitor a variation of the reflectivity in accordance with the variation in intensities of the reflected probe light **19** from the n-type semiconductor region **1a** depending upon whether or not the exciting light **20** has been irradiated, by irradiating the probe light **18**, generated by the Xe lamp **11**, onto the n-type semiconductor region **1a** on the substrate **1** or a pattern to be evaluated and by simultaneously irradiating the exciting light **20**, generated by the Ar ion laser **12**, onto the n-type semiconductor region **1a** on the substrate **1** while making the chopper **014** chop it at a frequency of 200 Hz. And, it is also configured to make a control system computer **15** control the operations of the heaters **4**, the chopper **14**, and the mass flow controller **8** and to receive a detection signal of the detector **13** so as to monitor the optical properties of the n-type semiconductor region **1a**. It is noted that the chopper **14** and the detector **13** for detecting the intensity of the reflected light have been configured so as to operate in synchronism with each other.

[0053]

Next, the principle of the optical evaluation method utilizing the variation in reflectivity will be described.

[0054]

The variation amount in reflectivity of the measurement light is a value (Δ**R/R**) obtained by dividing a difference Δ**R** between the reflectivity of the measurement light when the exciting light is irradiated onto a semiconductor region to be evaluated and the reflectivity when the exciting light is not irradiated by the reflectivity **R** when the exciting light is not irradiated onto the semiconductor region. It is considered that such a variation of reflectivity of the measurement light results from the following action. In general, when semiconductor is irradiated with light, carriers are excited by the light to increase the number thereof. Thereafter, when the carriers return to the original energy level, they are extinct while emitting light. An electric field is strengthened or weakened in accordance with such a variation in numbers of carriers. Thus, the reflection intensity when exciting light is irradiated is different from the reflection intensity when exciting is not irradiated. And, in the case where the structure of the semiconductor region is in a completely crystalline state, the variation amount of reflectivity is variable depending upon the wavelength of the measurement light. In other words, the spectrum in which the variation amount of reflectivity of the measurement light is plotted with respect to each wavelength of the measurement light shows characteristic variation corresponding to an energy gap, which indicates a difference between the bottom of the conduction band of a

semiconductor composing the semiconductor region and the top of the valence band thereof. Figure 6 shows an example thereof. Specifically, the variation amount of reflectivity ($\Delta R/R$) shows a relative minimum value in a wavelength region in which energy corresponds to about 3.3 eV, while the variation amount of reflectivity ($\Delta R/R$) shows a relative maximum value in a wavelength region in which energy corresponds to 3.5 eV.

[0055]

However, if a large number of structural disorders, such as crystallographic defects and an electron structure deviated from a normal state, exist in the semiconductor, then a trap level at a lower energy level comes to exist in the region. And since the region at a low energy level, which has been generated by such structural disorders, functions as a carrier-trapping layer, the increment in number of carriers is decreased and the variation amount of the electric field is also decreased. Thus, the larger the depth of the structurally disordered region, which has been generated by the implantation of impurity ions in the semiconductor region, or the larger the degree of disorder is, the smaller the variation amount ($\Delta R/R$) of reflectivity of the measurement light is. If the degree of structural disorder is so large, then the variation in reflectivity of the measurement light, resulting from the irradiation of the exciting light, becomes substantially zero. That is to say, in such a case, the spectrum in which the variation amount

of reflectivity of the measurement light is plotted with respect to each wavelength shows only a substantially constant small value.

[0056]

As can be seen from the foregoing, by monitoring the variation amount of reflectivity of the measurement light, information about the degree of recovery of the semiconductor region in the annealing process after impurity ions have been implanted can be obtained.

[0057]

Next, the time-dependent variation of the spectrum showing the variation amount in reflectivity of the probe light in the annealing process after the ion implantation will be described with reference to Figures **2** and **3**.

[0058]

Figure **2** is a spectral line diagram showing relations between an energy value proportional to the inverse (number of waves κ) of the wavelength λ of the probe light and the variation amount (Δ**R/R**) of reflectivity. However, since the axis of abscissas of Figure **2** can be substantially regarded as nothing but the representation of continuously variable wavelengths of the measurement light, Figure **2** shows spectra of the variation amounts (Δ**R/R**) of reflectivity with respect to the variation in wavelength after all. Moreover, in this embodiment, since the intensity of the probe light **18** to be irradi-

ated is constant, the variation amount (**ΔR/R**) of reflectivity has been calculated by dividing the difference **ΔR** between the intensity of the reflected probe light **19** when the exciting light **20** is irradiated and that when it is not irradiated by the intensity **R** thereof when the exciting light **20** is not irradiated. It is noted that the variation amount (**ΔR/R**) of reflectivity in Figure **2** is a relative value in which the initial state is assumed to be 0.

[0059]

In the state before the heat treatment process is started, arsenic (As) has already been introduced into the n-type semiconductor region **1a** on the substrate **1** housed in the reaction container **7** by performing an impurity ion implantation process under the conditions where a dose is set at about 1×10^{15} cm^{-2} and implantation energy is set at about 35 keV. The spectral line $\mathbf{S_0}$ shown in Figure **2** is a spectrum of the variation amount (**ΔR/R**) of reflectivity immediately after impurity ions have been implanted.

[0060]

The spectral line $\mathbf{S_{10}}$ in Figure **2** is a spectrum of the variation amount (**ΔR/R**) of reflectivity when the substrate **1** has been subjected to an annealing process in an environment of N_2 gas at 900℃ for 10 seconds by using the apparatus shown in Figure **1**. The spectral line $\mathbf{S_{25}}$ in Figure **2** is a spectrum of the variation amount (**ΔR/R**) of reflectivity when annealing is

performed under the same conditions for 25 seconds. As shown in this figure, as the annealing process proceeds, the spectral shape of the variation amount (Δ**R/R**) of reflectivity significantly varies. That is to say, the spectral shape represents the degree of recovery of Si crystallinity affected by the annealing process. It can be understood that, as recovery proceeds, the relative maximum peak value of the spectral line of the variation amount (Δ**R/R**) of reflectivity shifts upward and the relative minimum peak value thereof shifts downward.

[0061]

Thus, in this embodiment, particular attention is paid to the relative minimum peak value of a spectral line showing a larger variation and the degree of recovery in the annealing process after impurity ions have been implanted is monitored based on the relative minimum peak value in the spectral line. Since the spectral line has a relative minimum peak value at a point corresponding to the energy of about 3.3 eV (wavelength of 376 nm) as shown in Figure **2**, the variation amount of reflectivity of the reflected probe light **19** at a wavelength corresponding to the energy of 3.3 eV is assumed to be the relative minimum peak value in the spectral line.

[0062]

Figure **3** is a diagram showing a time-dependent variation of the relative minimum peak value of the spectral line in the annealing process for the substrate **1** by using the apparatus

shown in Figure **1** and by assuming that the variation amount of reflectivity of the reflected probe light **19** at a wavelength corresponding to the energy of 3.3 eV is the relative minimum peak value in the spectral line. As shown in this figure, since the recovery of the semiconductor region proceeds with the passage of the annealing process time, the relative minimum peak value increases as the time elapses. It could be confirmed by Raman spectroscopy that, even when the annealing process is completed at a point in time when the relative minimum peak value reaches -12.0 (35 seconds), the crystallinity of the semiconductor region (Si crystals in this embodiment) has recovered sufficiently.

[0063]

Thus, in this embodiment, by controlling the annealing treatment process based on not the annealing process time which has been determined, with some degree of margin, by an experiment performed beforehand on a wafer to be monitored, but the variation of the relative minimum peak value of the spectral line in the actual annealing process, the fabrication of a device having not only stable crystallinity but also a stable impurity profile is realized. Specifically, by monitoring the variation amount (Δ**R/R**) of the reflectivity at a particular wavelength (energy region) during the annealing process, a stable annealing treatment process and the fabrication of a device having excellent characteristics are realized.

[0064]

Furthermore, in this embodiment, the time required for the relative minimum peak value to reach -12.0 was controlled and periodic maintenance was performed on the heat-treating apparatus of this embodiment at a point in time when the time exceeded 40 seconds. Figure **7** shows a variation of the annealing time required for the relative minimum peak value in the spectral line to reach -12.0 with respect to the number of processed wafers. It is presumably because the components of a device are degraded that the time required for the relative minimum peak value to reach -12.0 becomes longer in accordance with the number of processed wafers in this way. Although some trouble such as defective contact resistance in a semiconductor region occurs if annealing has been performed for more than 40 seconds in accordance with a conventional control method, the control technique of the present invention can suppress the occurrence of such trouble. That is to say, combining the optical control technique of this embodiment with a process time control technique also enables a process control on a heat treatment process, which has been hard to be implemented by a conventional method. As a result, stable operation is achieved.

[0065]

(Second Embodiment)

Next, the second embodiment about a method for measuring an impurity concentration will be described.

[0066]

Figure **4** shows an optical monitoring system in the second embodiment. As shown in this figure, a Xe lamp **502** for generating probe light (wavelength: 376 nm and energy: 3.3 eV) as measurement light is provided. The probe light **507** generated by the Xe lamp **502** is reflected by a mirror **506** and then provided to the n-type semiconductor region **103a** (a specific resistance: about 0.02 Ωcm) on a silicon wafer **103** disposed on a wafer stage **504**. The impurity has been continuously introduced into the n-type semiconductor region **103a**, which has been subjected to a heat treatment. And, the reflected probe light **508** reflected by the n-type semiconductor region **103a** is passed through the mirror **506** so as to be provided to a microscope system **505** and then the intensity thereof is detected by a system for observation and analysis **509**. In this embodiment, the irradiation of the probe light **507** onto the region to be observed and the take-out of the reflected robe light **508** can be performed in a direction vertical to the surface of the sample by using the microscope system **505** and the mirror **506** in combination.

[0067]

In addition, an Ar ion laser **503** having an intensity of 5 W for generating exciting light to be irradiated onto the n-type

semiconductor region **103a** is also provided. The exciting light **511** from the Ar ion laser **503** is chopped by a chopper **510** at a frequency of 100 Hz and intermittently irradiated onto the n-type semiconductor region **103a** of the silicon wafer **103**. The diameter of the exciting light **511** can be converged by a lens **510** down to $50\mu m\phi$. And, the value (Δ**R/R**) obtained by dividing the difference Δ**R** between the reflection intensity of the measurement light (probe light) when the exciting light **511** has been irradiated and that when it has not been irradiated by the reflection intensity **R** when the exciting light **511** has not been irradiated is detected by the system for observation and analysis **509** as a variation amount of reflection intensity, as described above. The variation in variation amount of reflection intensity of the probe light is monitored by the above-described configuration. It is noted that data about the reflection intensity measured by the system for observation and analysis **509** is transmitted to a heat treatment control system (not shown) via a signal line. The chopper **510** and a detector for detecting the intensity of the reflected light are configured so as to operate in synchronism with each other.

[0068]

Figure **5** shows a relationship between the relative minimum peak value in the spectral line of the variation amount of reflectivity obtained by actual observation and the impurity dose when an impurity is introduced. The impurity is arsenic (As),

the doses used in the experiments are 1.0×10^{15} cm^{-2}, 5.0×10^{15} cm^{-2}, 5.0×10^{14} cm^{-2} and 1.0×10^{14} cm^{-2}, and in any of theses cases, the acceleration energy for ions is 150 keV. Also, the heat treatment is performed in an environment of N_2 gas at 850℃ for 1 hour. A spectrum of the variation amount (**ΔR/R**) of reflectivity when the does is 1.0×10^{15} cm^{-2} is shown in Figure **6**.

[0069]

As can be seen from Figure **5**, the relative minimum peak value of the variation amount (**ΔR/R**) of reflectivity of a sample implanted with the impurity is turned into a negative value of a larger magnitude as the dose increases. That is to say, the variation amount (**ΔR/R**) of reflectivity reflects the impurity concentration. And this means that the ultimate impurity concentration in the substrate after the heat treatment can be known by monitoring the variation amount (**ΔR/R**) of reflectivity. Thus, by performing the implantation of impurity ions and heat treatment for diffusion until the relative minimum peak value reached a certain value, it is possible to precisely regulate it to a desired impurity concentration in the n-type semiconductor region **103a**.

[0070]

In the above-described embodiment, a heat treatment process for recovering the structural disorders resulting from the defects caused by the implantation of impurity ions and the

like has been described. However, the heat treatment of the present invention is not limited to such an embodiment, but is also applicable to a heat treatment process for recovering the structural disorders resulting from the defects caused by etching and the like.

[0071]

[Effects of the Invention]

According to the method for evaluating a semiconductor device of Claims 1 to 5, the optical properties of an n-type semiconductor region which has been doped with an impurity are monitored and the impurity concentration in the n-type semiconductor region is evaluated based on the results. Thus, the impurity concentration in the n-type semiconductor region can be detected precisely by utilizing the fact that the penetration depth of light into a semiconductor substrate is shallow. Consequently, it is possible to provide a method for evaluating a semiconductor device, which is applicable to the on-the-spot observation during a fabrication process.

[0072]

According to the method for heat-treating a semiconductor device of Claims 6 to 13, the optical properties of an n-type semiconductor region, in which a structural disorder has been generated during a process, are monitored and a heat treatment for recovering the structural disorder of the n-type semiconductor region is performed while controlling the conditions based on the results. Thus, while precisely sensing the struc-

tural disorder in the n-type semiconductor region by utilizing the fact that the penetration depth of light into the semiconductor substrate is shallow, it is possible to try to fabricate a semiconductor device of high quality through a stable heat treatment process.

[0073]

According to the apparatus for heat-treating a semiconductor device of Claims 14 to 20, means for heating a semiconductor region with a substrate disposed within the processing chamber; means for intermittently irradiating exciting light onto the semiconductor region; means for irradiating measurement light onto the semiconductor region; means for detecting the reflected light of the measurement light from the semiconductor region; means for calculating a variation amount of reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated; and means for controlling a heat treatment based on the variation amount of reflectivity of the measurement light are provided. Thus, while grasping the optical properties of the semiconductor region with certainty by utilizing the fact that the variation amount in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated is decreased if there is an irregular region in the semiconductor region, the heat treatment process can be controlled rapidly and precisely. Consequently, it is possible to try to provide an apparatus for

heat-treating a semiconductor device which can carry out a stable operation and a precise impurity diffusion process.

[0074]

According to the method for controlling a heat-treating apparatus of Claims 21 to 27, when the heat-treating apparatus of Claims 14 to 20 is used, a heat treatment is performed until the variation amount of reflectivity reaches a predetermined value. In the meantime, when the predetermined time exceeds a critical value, the maintenance of the heat-treating apparatus is performed. Thus, it is effectively possible to prevent defects, resulting from the increase in heat treatment time because of the deterioration of the components within a processing chamber, from being generated.

[Brief Description of the Drawings]

[Figure 1]

A cross-sectional view schematically showing the configuration of an apparatus for heat-treating a semiconductor device according to the first embodiment.

[Figure 2]

A spectral line diagram showing the variation in shape of the spectrum of the variation amount of reflectivity with respect to the annealing process time in the first embodiment.

[Figure 3]

A diagram showing the variation in relative minimum peak values with respect to the annealing process time in the first embodiment.

[Figure 4]

A perspective view schematically showing the configuration of an apparatus for optically measuring an impurity concentration in the second embodiment.

[Figure 5]

A diagram showing the relationship between a dose and a relative minimum peak value during the ion implantation in the second embodiment.

[Figure 6]

A spectral line diagram showing the variation amount of reflectivity after arsenic ions have been introduced at a dose of 1×10^{15} cm^{-2} and the heat treatment has been performed.

[Figure 7]

A diagram showing the variation of the time required for a relative minimum peak value to reach a predetermined value with respect to the number of processed wafers during the heat treatment in the first embodiment.

[Description of the Reference Numerals]

1 semiconductor substrate

1a n-type semiconductor region

2 wafer susceptor

3 quartz tube

4 heater

5 quartz window for observation

6 quartz window for observation

7 reaction container

8 mass flow controller

9 gas inlet port

10 gas outlet port

11 Xe lamp

12 Ar ion laser

13 reflected light observation system

14 laser chopper

15 control system computer

18 incident probe light

19 reflected probe light

20 exciting light

103 silicon wafer

103a n-type semiconductor region

502 Xe lamp

503 Ar ion laser

504 wafer stage

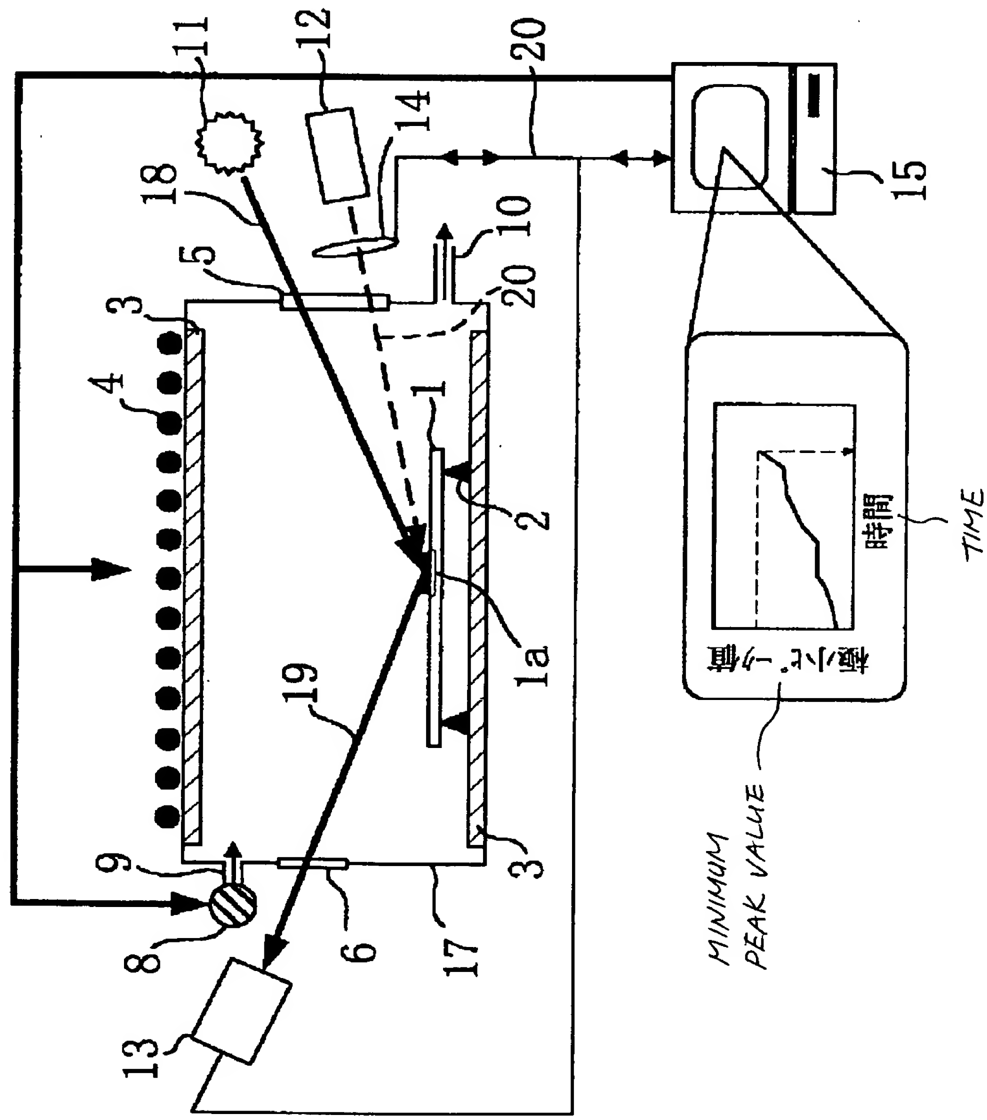
505 microscope system

506 mirror

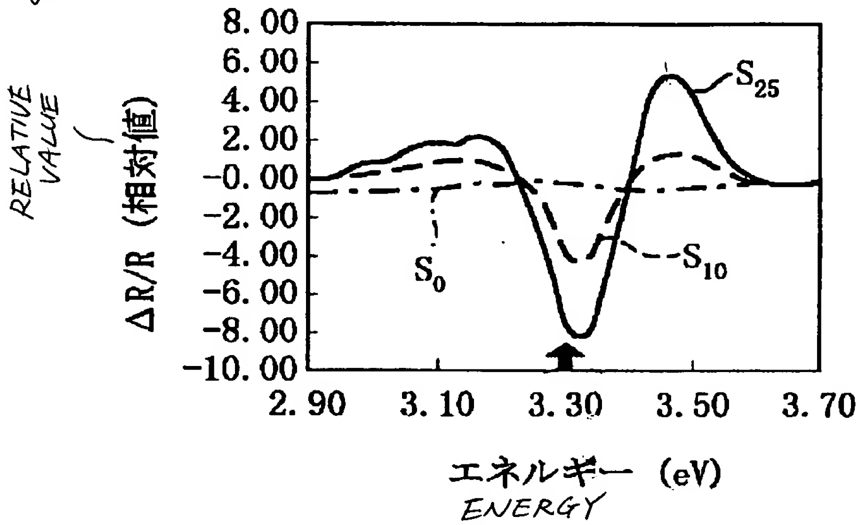
509 system for observation control and analysis

【書類名】　　　図面
[Name of the Document]　DRAWINGS

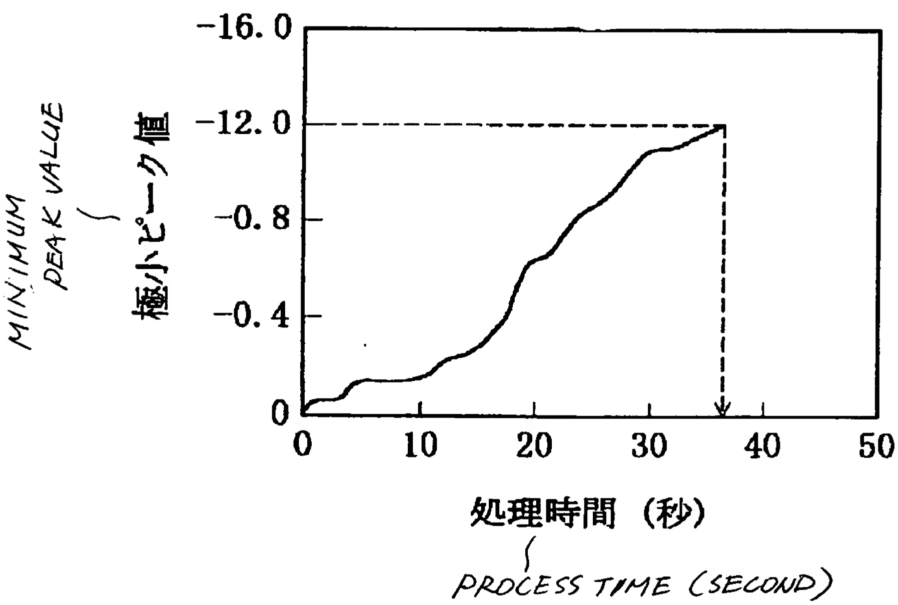
【図１】
[Figure 1]



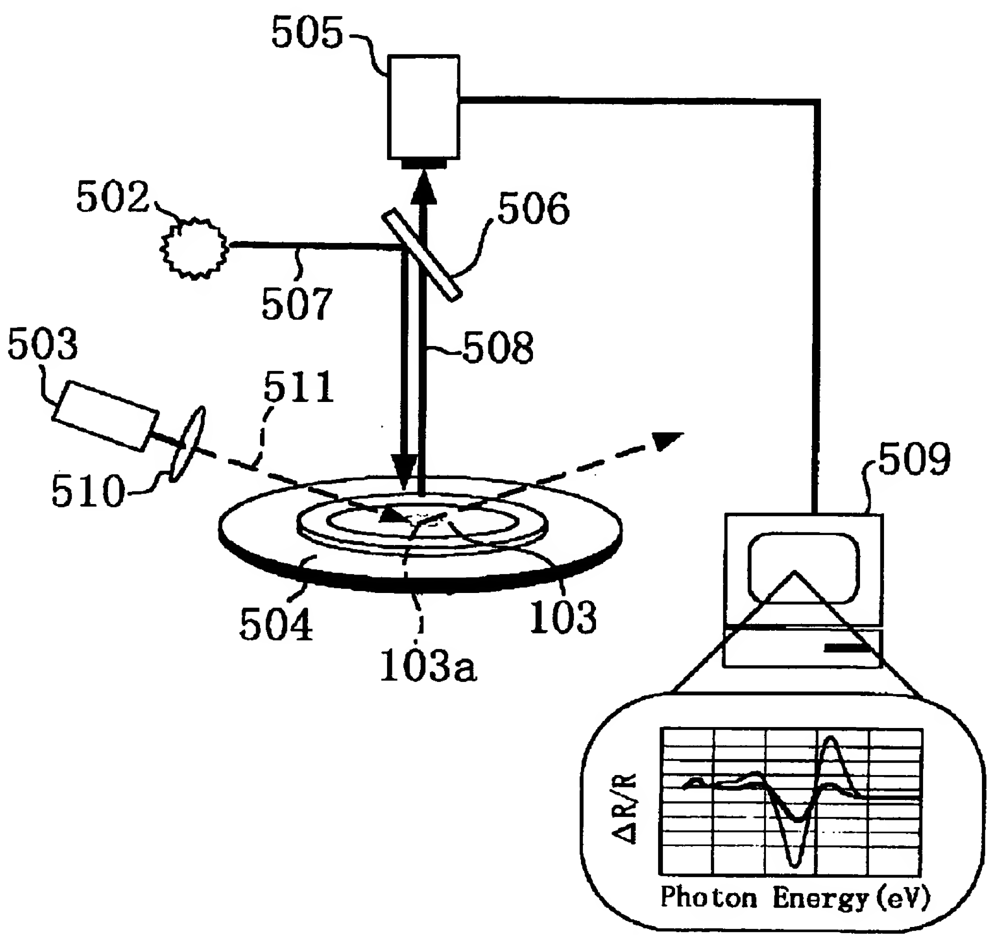
【図２】
[Figure 2]



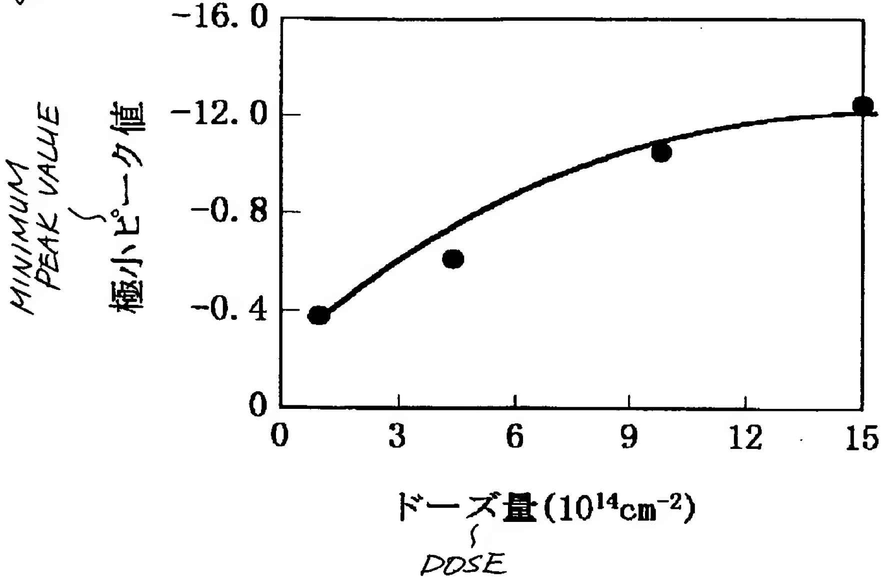
【図３】
[Figure 3]



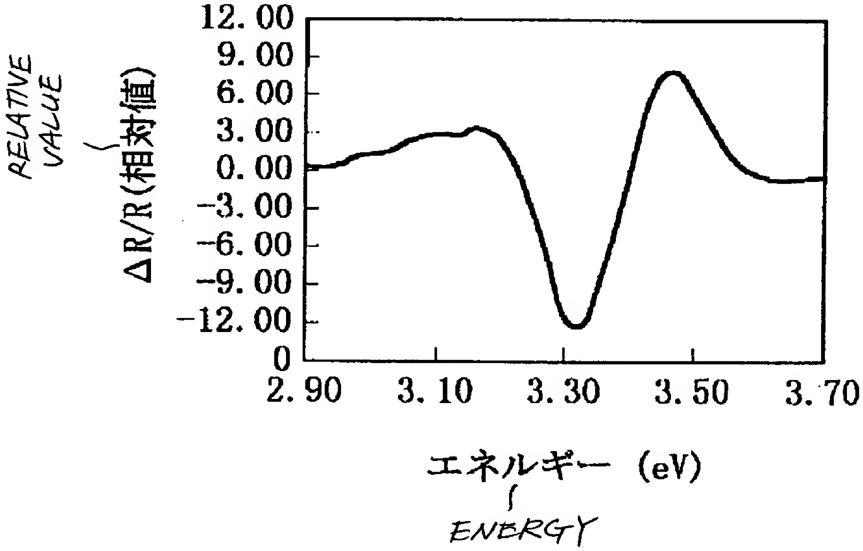
【図４】
[Figure 4]


505
502
506
507
508
503
511
510
509
504
103
103a
ΔR/R
Photon Energy (eV)

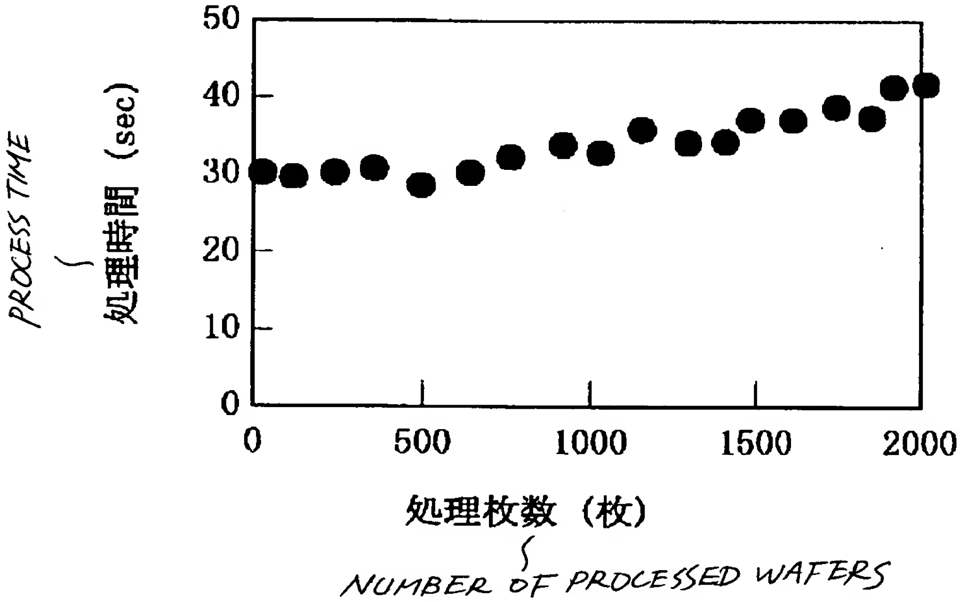
【図５】
[Figure 5]



【図６】
[Figure 6]



【図７】
[Figure 7]


50
40
30
20
10
0
処理時間（sec）
PROCESS TIME
0
500
1000
1500
2000
処理枚数（枚）
NUMBER OF PROCESSED WAFERS

[Name of the Document] ABSTRACT

[Abstract]

[Problem] To realize a control of a heat treatment process while grasping the actual recovery state of a semiconductor region having a structural disorder and detecting the impurity concentration in introducing impurity during a process.

[Means for Solving the Problem] A silicon wafer **1**, having an n-type semiconductor region **1a** with an impurity introduced, is disposed within a reaction container **7**. In a heat treatment process of this silicon wafer **1**, measurement light **18** is irradiated onto the n-type semiconductor region **1a** and exciting light **20** is irradiated intermittently thereto, thereby making a reflected light observation system **13** monitor the variation amount of reflectivity of the reflected measurement light **19** depending upon whether or not the exciting light **20** has been irradiated. In view of the variation of the peak value (relative minimum peak value, in particular) in the spectrum of the variation amount of reflectivity in accordance with the recovery to the normal state through heat treatment and the variation of the peak value in the spectrum in accordance with the amount of the impurity introduced, a control system computer **15** controls the conditions during the heat treatment process by using the monitoring results.

[Selected Figure] Figure **1**